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Proposed methodology for the study of the level of emerging risk from exposure to hand-arm vibrations in manufacturing environments

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Abstract

Occupational exposure to vibrations, regulated by Directive 2002/44/EC, is currently on the rise. This situation makes it necessary to increase knowledge of the exposure, considering amongst other factors, its nature as an emerging risk.
To do so, a methodology has been developed for application in manufacturing environments. This has been designed by combining the principles of the DMRA Technique with a theoretical framework of new and emerging risks established from recent research.
This methodology grades the Emerging Risk Level (ERL) on 9 levels, from 'not at all significant' (ERL=1) to "fully significant" (ERL=9). This methodology has been applied to hand-arm vibrations generated by using an electric disc grinder. Thirty-two entries from the National Institute of Safety and Health at Work (INSHT) 'Vibra' database have been considered for this.
The main findings indicate that 55% and 36% of cases give rise to 'moderately significant' (ERL=7) and 'very significant' (ERL=8) emerging risk, respectively.

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Keywords: DMRA Technique; hand-arm vibration; measurement; new and emerging risk;

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1. Introduction

The legal framework of occupational safety and health in Spain is well developed from transposing numerous European directives. These directives include Directive 2002/44/EC on the exposure of workers to vibrations [1], which was transposed to Spanish law by Royal Decree (RD) 1311/2005 on the protection of the health and safety of workers against vibration-related risks [2].

RD 1311/2005 differentiates between hand-arm vibrations and whole-body vibrations. This regulation defines hand-arm vibrations as the mechanical vibration that, when transmitted to the human hand-arm system, entails risks to the health and safety of workers, in particular vascular, bone or joint, neurological or muscular disorders. Whole-body vibration is the mechanical vibration that, when transmitted to the whole body, entails risks to the health and safety of workers, in particular lower-back morbidity and trauma of the spine.

Currently, as indicated by Álvarez [3], occupational exposure to vibrations is on the rise. For example, the increase in exposure to vibrations in Spain between 2007 and 2011 increased from 13.5% to 15.9% [4]. At present, 20% of EU workers and 19% of those in Spain are exposed to vibrations from tools or machinery for at least a quarter of their working day, according to the Sixth European Survey on Working Conditions [5].

This situation has meant that in recent years both the EU and the Spanish government have made efforts to control and prevent the damage caused by vibrations [3]. Aside from these efforts it is necessary to improve knowledge of the exposure to vibrations, considering among other aspects, any new and emerging risks of note.

As such, the main objective sought with this paper is the development of a proposed methodology for studying the exposure to hand-arm vibrations in manufacturing environments, as an emerging risk.

The development of this proposed methodology brings together the principles of the Decision Matrix Risk-Assessment (DMRA) technique (consequence/probability matrix) described in the ISO 31010:2011 Standard [6] with the new and emerging risk (NER) theoretical framework developed by Brocal et al. [7].

2. Theoretical concepts

The process for assessing the risk from occupational exposure according to RD 1311/2005 consists of determining parameter A(8), which depends on the time of exposure and the magnitude of the vibration expressed through its acceleration, and comparing this parameter A(8) with reference values.

$$\mathrm{A}(8) = a_{hv} \cdot \sqrt{\frac{T}{8}} \tag{1}$$

where a_{hv} is the total equivalent vibration value in m/s^2 and T is the exposure time in hours.

Subsequently, parameter A(8) will be compared with exposure levels that are established in RD 1311/2005 itself and that are included in Table 1 in the case of hand-arm vibrations.

Table 1. Niveles de exposición a VMB (RD 1311/2005).

Intervals of daily exposure to vibrations A(8)	Level of exposure
$A(8) \leq 2.5$ m/s^2	Does not exceed the exposure action value
2.5 m/s^2 < A(8) ≤ 5 m/s^2	Above the exposure action value, but below the exposure limit value
A(8) > 5 m/s^2	Above the exposure limit value

The same year that the aforementioned RD 1311/2005 came into force, the European Agency for Safety and Health at Work, EU-OSHA, began to study the so-called New and Emerging Risks (NER), broadly defined as 'any new and increasing risk'. Of the first reports published on this subject by the EU-OSHA, the most relevant to this paper have been those on the developments in the field of physical risks by Flaspöler et al. [8], where other NER associated to vibrations were identified, such as hand-arm and whole-body vibrations.

The full definition of NER [8-11], which has been codified (Ci) and modelled by Brocal and Sebastián [12,13] as well as integrated into a theoretical framework in the material developed by Brocal et al [7], is as follows. Any occupational risk that is both new and increasing:

- By ‘new’ it is meant that:

  C1. The risk was previously unknown and is caused by new processes, new technologies, new types of workplace, or social or organisational change; or,
  C2. A long-standing issue is newly considered as a new risk due to a change in social or public perceptions; or,
  C3. New scientific knowledge allows a long-standing issue to be identified as a risk.

- The risk is ‘increasing’ if the:

  C4. The number of hazards leading to the risk is growing; or
  C5. The likelihood of exposure to the hazard leading to the risk is increasing (exposure level and/or the number of people exposed); or
  C6. The effect of the hazard on workers’ health is getting worse (seriousness of health effects and/or the number of people affected).

3. Proposed methodology

After applying the theoretical framework developed by Brocal et al. [7], among the various causes that may result in an exposure to vibrations being considered a NER, Flaspöler et al. [8] report an increase in the exposed working population due to the technological and industrial development in European countries.

Such a consideration continues to be relevant today, as indicated in the introduction. Likewise, this circumstance is compatible with the codified conditions C4, C5 and C6, in other words, with the conditions that determine the emerging characteristics of the risk from exposure to vibrations.

The conditions C1, C2 and C3 however, determine the new characteristics of a certain risk. In the case of vibrations the condition C2 can be considered from the publication of Directive 2002/44/CE regarding vibrations and its subsequent transposition into RD 1311/2005.

As such, from the set of conditions that establish exposure to hand-arm vibrations as an NER, the conditions related with the emerging qualities acquire greater relevance in terms of effect in time. For this reason the proposed methodology will focus on these emerging qualities, in order to determine the Emerging Risk Level (ERL) linked to hand-arm vibrations.

Therefore, the proposed methodology establishes an ERL classification divided into nine levels, from “not at all significant” (ERL=1) to “fully significant” (ERL=9). To obtain a level, a system has been designed with three matrices, A, B and C, which are shown in Tables 2, 3 and 4, respectively.

Table 2. Relative importance of exposed workers (RIEW).

	A MATRIX	RNEW RNEW< 33%	 33% ≤ RNEW < 66%	 RNEW ≥ 66%
RPMS	RPMS< 33%	1	1	2
	33% ≤ RPMS < 66%	2	3	3
	RPMS ≥ 66%	3	4	4

Table 3. Probability.

B MATRIX		RIEW (A MATRIX) 1	2	3	4
A (8)	A (8) < 2.5	I	I	I	II
	2.5 ≤ A (8) < 5	II	II	II	III
	A (8) ≥ 5	III	III	III	IV

Table 4. Emerging Risk Level (ERL).

C MATRIX		PROBABILITY (B MATRIX) I	II	III	IV
CONSECUENCE	POE < 50%	1	2	2	3
	POE = 50 %	3	4	4	5
	POE > 50%	6	7	8	9

The sequential application of this system allows the DMRA technique to be transferred to the C Matrix (Table 4). This matrix is established by the Consequence and Probability variables, so the ERL is determined through the combination of values adopted by these variables.

The graduation and determination of the values associated with the Consequence and Probability values are described below.

3.1 Graduation of the consequence variable

The C6 Condition has been considered for grading the Consequence variable on workers' health and safety: 'the effect of the hazard on workers' health is getting worse (seriousness of health effects and/or the number of people affected).

The results of the Seventh National Survey on Working Conditions 2011 [4] have been considered to perform this grading, for occupations that most frequently entail hand-arm vibrations in the workplace. The occupations considered are: traditional industry workers, industrial workers, mechanics and workshop employees.

In line with condition C6, it is considered that any exposure to hand-arm vibration generates some type of consequence or negative effect for the health and safety of exposed workers.

As such, the Consequence variable has been graded in terms of the percentage of population occupationally exposed (POE) in the aforementioned employment. The grading is as follows: minor consequences (PLE <50%), average consequences (POE = 50%) and major consequences (POE > 50%).

3.2 Graduation of the probability variable

The C5 Condition has been considered for the grading of the Probability variable: 'exposure to the hazard leading to the risk is increasing (exposure level and/or the number of people exposed).'

A 'B' Matrix has been designed for this which combines the variables 'Risk Level - A(8)' and 'Relative importance of exposed workers (RIEW).' With this matrix, probability is classified into four levels, where a lower level relates to a lesser probability compared to another with a higher probability.

The 'Risk Level' (which relates to the level of exposure) has been graded according to the various intervals of the parameter A(8) for hand-arm vibrations as provided in RD 1311/2005: (values in m/s^2): A(8) < 2.5; 2.5 ≤ A (8) < 5; A (8) ≥ 5.

The 'Relative importance of exposed workers (RIEW)' (relating to the number of workers exposed) has been graded into four levels, where a lower level relates to a lesser relative importance of workers exposed compared to another with a higher value.

An ‘A’ Matrix has been designed to determine these levels, which combines the variables ‘Relative percentage of manufacturing sectors (RPMS)’ and ‘Relative number of exposed workers (RNEW)”.

To grade the RPMS variable, the following intervals have been considered: RPMS < 33%; 33% ≤ RPMS < 66%; RPMS ≥ 66%. To calculate this variable the International Standard Industrial Classification of all Economic Activities (ISIC) [14] has been used. Of its 21 sections, the contents of Section C 10-33 have been noted as of interest for manufacturing engineering: the manufacturing industries contained in the divisions/descriptions from 10 to 33. As such, the value of this variable is determined by the percentage of the divisions of interest compared to the total divisions contained in the manufacturing industries section described in the aforementioned document.

To grade the RNEW variable, the following intervals have been considered: RNEW < 33%; 33% ≤ RNEW < 66%; RNEW ≥ 66%. To calculate this variable the Industrial Companies Survey [15] has been used. Therefore, the value of RNEW is determined by the percentage of active workers in the categories of interest compared to the total number of active workers in the manufacturing industry.

4. Emerging Risk Level (ERL) Practical case: Electric angle grinder hand-arm vibration exposure

As a practical case the ERL associated with hand-arm vibrations will be determined for the use of an electric angle grinder, a tool widely-used in industrial environments [16].

In this practical case, the total equivalent vibration value has been considered, a_{hv}, which for this type of tool is included in the INSHT’s Vibra database [17], taking into consideration the conditions of use for the manufacturing sector. There has been no uncertainty surrounding any tool as all of the values were found in the aforementioned database; this in itself represents a problem that has not yet been resolved [18].

To this regard, 32 entries have been identified, whose data are included in Table 6. For each case, the total equivalent vibration value has been verified as falling within the interval considered for the Non-binding guide to good practice with a view to implementation of Directive 2002/44/EC [19].

Below, following the proposed methodology the values are calculated first for the Consequence and Probability variables. Subsequently these values determine the ERL for each tool of those considered in the INSHT’s Vibra database.

4.1 Calculating consequences and probability

Using the criteria described in methodology, the value of the Consequence variable has been calculated to be 67.2% (traditional industry workers: 17.7%; industrial workers: 19,4%; mechanics and workshop employees: 30.1%). This value corresponds with major consequences (>50%).

In terms of determining the Probability, it is necessary to calculate the following variables: ‘Relative importance of exposed workers (RIEW)’ and ‘Risk Level – A(8)’. Calculation of the first variable also requires the calculation of the ‘Relative percentage of manufacturing sectors (RPMS)’ and the ‘Relative number of exposed workers (RNEW)’.

In the case of the electric axle grinder, the sectors included in section C with divisions 16, 25, 28, 29, 30, 31, 32 and 33 of the ISIC document can be considered reference sectors for use in manufacturing processes (as well as general industrial maintenance tasks). This represents an RPMS of 34.8% in relation to the 23 activity categories for section C (manufacturing industries).

Bearing in mind the previously selected categories, the RNEW value is 59% (52.6% compared to 89.2 %) with regards the total number of active workers in manufacturing included in the document for manufacturing industries [16].

With the two values obtained for RPMS and RNEW, a ‘Relative importance of exposed workers (RIEW)’ of 3 can be obtained from matrix A.

In terms of calculating the ‘Risk Level’, it is necessary to obtain the value of parameter A(8) for each tool considered. For this, as shown in the equation (1), the total equivalent vibration value (a_{hv}) and the exposure time (T) are required.

As previously indicated, the value of the vibration is obtained from the INSHT's Vibra database. In terms of the determination of the exposure time, in the case of the considered tool, the CEN/TR 15350-2013 [20] standard provides the standard exposure times shown in Table 5. Both criteria are compatible with RD 1311/2005, which indicates that parameter A(8) can be determined using criteria based on estimation or measurement.

Table 5. Usage time to Electric Angle Grinder

Electric Angle Grinder	Industrial Use (hours)
< 1500W	3
≥1500 W	2

For comparative purposes, the two exposure times shown in Table 5 have been used to calculate parameter A(8) for each tool, regardless of their wattage. As such, with the values calculated for RIEW and parameter A(8), matrix B provides the values for the Probability variable for each tool, which vary between 1 and 3.

4.2 Determination of the ERL

Matrix C has been used to determine the ERL, considering the values obtained in the previous section for the Consequence and Probability variables for each tool. Table 6 summarises the results obtained for the various angle grinders identified in the Vibra database (a_{hv}), as well as those associated with parameters A(8) and the ERL for an exposure time of 2 and 3 hours.

Table 6. A(8) Level & Emerging Risk Level (ERL) Evaluation: Electric Angle Grinder

Brand	a_{hv} (m/s^2)	A(8) (m/s^2) (T =2 h)	ERL (T=2h)	A(8) (m/s^2) (T=3 h)	ERL (T=3h)	Brand	a_{hv} (m/s^2)	A(8) (m/s^2) (T =2 h)	ERL (T=2h)	A(8) (m/s^2) (T=3 h)	ERL (T=3h)
ATLAS COPCO	7.8	3.90	7	4.78	7	BOSCH	5.89	2.95	7	3.61	7
ATLAS COPCO	6.08	3.04	7	3.72	7	BOSCH	7.44	3.72	7	4.56	7
BLACK & DECKER	6.33	3.17	7	3.88	7	DEWALT	9.11	4.56	7	5.58	8
BOSCH	6.07	3.04	7	3.72	7	DEWALT	13.69	6.85	8	8.38	8
BOSCH	6.55	3.28	7	4.01	7	DEWALT	7.3	3.65	7	4.47	7
BOSCH	8.96	4.48	7	5.49	8	FEIN	6.73	3.37	7	4.12	7
BOSCH	7.4	3.70	7	4.53	7	HILTI	3.24	1.62	6	1.98	6
BOSCH	5.4	2.70	7	3.31	7	METABO	4.78	2.39	6	2.93	7
BOSCH	6.6	3.30	7	4.04	7	METABO	9.68	4.84	7	5.93	8
BOSCH	5	2.50	7	3.06	7	METABO	13.02	6.51	8	7.97	8
BOSCH	11.1	5.55	8	6.80	8	METABO	8.28	4.14	7	5.07	8
BOSCH	18.2	9.10	8	11.15	8	METABO	3.31	1.66	6	2.03	6
BOSCH	10.84	5.42	8	6.64	8	METABO	18.4	9.20	8	11.27	8
BOSCH	8.36	4.18	7	5.12	8	METABO	19.23	9.62	8	11.78	8
BOSCH	9.9	4.95	7	6.06	8	PROTOOL	4.22	2.11	6	2.58	7
BOSCH	9	4.50	7	5.51	8	HILTI	3.24	1.62	6	1.98	6

5. Analysis of results

The average value A(8) obtained for an exposure time of 2h is 3.81 m/s^2, with a typical deviation of 2.05 m/s^2 (Fig. 1a). For an exposure time of 3h, the average value is 4.67 m/s^2 and its typical deviation is 2.52 m/s^2 (Fig. 1.b). To this regard it notably follows that, on the whole, a one-hour increase in exposure time involves a clearer transition from the exposure action values to the exposure limit values outlined in Tabla 1.

In terms of the ERL values (2h), for approximately 13% of the tools considered from the Vibra database an ERL of 6 is obtained, with an ERL of 7 obtained for approximately 62% of them, and an ERL of 8 for 25% (Fig. 2).

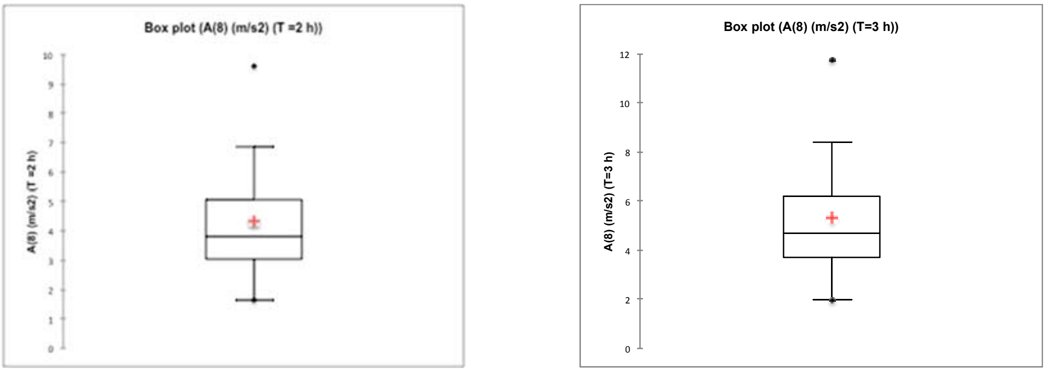

Fig. 1. Box plot A (8): (a) t = 2h; (b) t =3h.

In relation to the ERL values (3h), approximately 6% of the tools obtained an ERL of 6, approximately 47% obtaining level 7 and another 47% of the tools in the Vibra database obtaining an ERL of 8 (Fig. 2).

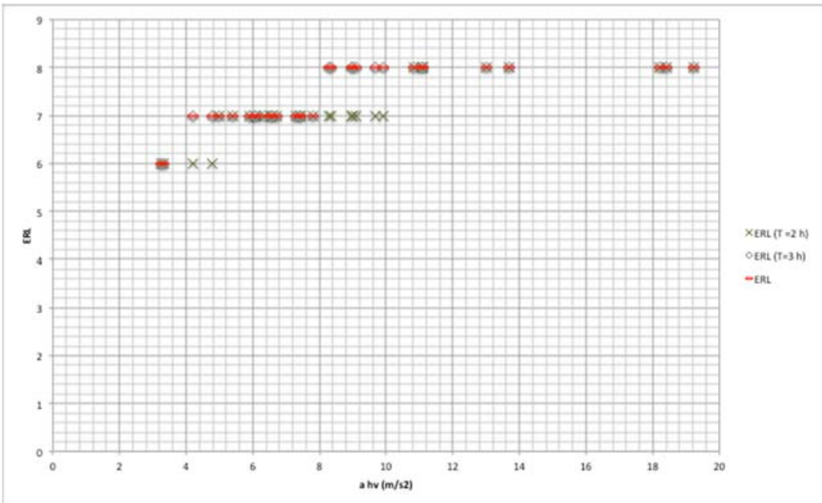

Fig. 2. ERL (2h) and ERL (3h).

Comparing the ERL values for 2h and 3h, it is observed that they are greater for an exposure time of 3h in only 28% of the cases. This outcome is evidently in line with the comparison of the values of the parameter A(8), or in other words, 47% of the tools exceed the limit values for an exposure time of 3h compared to 25% when the exposure is only 2h.

The ERL values for 2h and 3h can be considered 'moderately significant' in 55% of the cases (average percentage for cases with an ERL of 7), as well as 'very significant' for 36% (the average percentage for cases with an ERL of

8). No cases have been identified with an ERL of 9. The ERL values considered ‘moderately significant’ correspond to A(8) parameter values that fall within the interval of the action values defined in Tabla 1. The ERL values that are considered ‘very significant’ relate to parameter A(8) values that exceed the limit values. This relationship is considered to be coherent.

6. Conclusions

A proposed methodology has been developed which allows the study of exposure to arm-hand vibrations in manufacturing environments, considering their emerging characteristics by determining the ERL value. This methodology has been applied to a practical case. From this, coherent ERL values have been obtained with intervals of the parameter A(8) defined by RD 1311/2005. Nevertheless, the developed methodology must be considered as an initial proposal, due mainly to its statistical limitations.

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